Institute of Experimental Morphology, Pathology and Anthropology with Museum
Bulgarian Anatomical Society

Acta Morphologica et Anthropologica, 32 (3-4)
Sofia ● 2025

Perihilar Branching Patterns of Renal Arteries and Extrarenal Length of Arterial Branches: A Study Using Peripheral Angiography

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Renal arteries supply blood to the kidneys, and variations in their branching patterns and extra-renal lengths can influence surgical and interventional outcomes. This is critical for clinical practice.A cross-sectional study of 100 kidneys (50 right, 50 left) from patients undergoing peripheral angiography classified perihilar branching into four types: Type I (single artery, normal bifurcation), Type II (multiple arteries), Type III (early branching), and Type IV (complex branching). Extrarenal lengths were measured from the renal hilum to the first arterial branch, with significance set at $p<0.05$.Type I was most common (60% right, 62% left), followed by Type II (18–20%), Type III (14–15%), and Type IV (5–6%). Mean extrarenal lengths were 20.5 mm (right) and 22.1 mm (left), with no significant difference ($p=0.24$). Type I is the standard renal artery configuration, while variations (Types II–IV) underscore the need to account for anatomical differences to optimize surgical planning.

Key words: renal artery anatomy, perihilar branching patterns, extra renal length, peripheral angiography, renal vascular variations

Introduction

The renal arteries are vital blood vessels responsible for supplying oxygenated blood to the kidneys, playing a crucial role in maintaining renal function. Their anatomical configuration is important not only for normal kidney function but also for guiding surgical and interventional procedures. Variations in the renal artery structure, particularly in the perihilar region where the artery branches before entering the kidney, can have significant clinical implications. These variations may impact the outcomes of renal surgeries, diagnostic procedures, and interventions, such as renal transplantation, nephrectomy, renal artery revascularization, and stenting. Given the advancements in renal surgery and interventional techniques, understanding these variations is increasingly vital for ensuring optimal clinical outcomes [1,8].

In addition to anatomical variations, knowledge of the extrarenal length of arterial branches – the distance from the renal hilum's bifurcation to the first arterial division – provides important insights for clinicians when planning surgical or interventional procedures [12]. The length and branching patterns of renal arteries can vary significantly among individuals, whether due to anatomical differences or congenital anomalies. These variations range from a simple bifurcation (Type I) to multiple or early branching (Types II and III), and even more complex configurations, such as trifurcations (Type IV). Research in recent years has emphasized how these variations influence renal health, particularly in conditions like renovascular hypertension and renal transplantation [10, 11]. Understanding these branching patterns is crucial for improving diagnostic accuracy and tailoring interventions for individuals with complex renal vascular anomalies.

The classification of renal arterial morphology, used in this study, is based on Shoja et al.'s (2008) classification system [15]. Renal artery branching patterns were categorized into two types: fork-type and ladder-type. In the fork-type configuration, there is a single point of division, which can either be duplicated (Type I, with an upper and lower branch) or triplicated (Type II, with upper, middle, and lower branches). In contrast, the ladder-type configuration (Type III) involves sequential branching points, resulting in multiple branches along the artery.

Peripheral angiography, especially digital subtraction angiography (DSA), is a non-invasive imaging technique that remains essential for visualizing the renal vascular anatomy. Recent advancements in DSA technology have enhanced the clarity and detail of renal artery visualization, particularly for perihilar branching patterns and the extrarenal lengths of arterial branches [4,18]. These advancements have facilitated a more accurate understanding of renal artery anatomy, which is critical for the success of renal surgeries and interventions. Despite significant advancements in imaging technology, renal angiography continues to be the gold standard for diagnosing renal artery diseases. When performed with appropriate techniques, it delivers detailed anatomical visualization of the renal arteries, including their segmental and subsegmental branches, providing critical information for the diagnosis and management of renal vascular disorders. The study was aimed to investigate the perihilar branching patterns of the renal arteries and the extrarenal length of their branches using peripheral angiography with objectives to categorize the perihilar branching patterns of the renal arteries in both the right and left kidneys, to measure and compare the extrarenal lengths of the arterial branches in the right and left kidneys and to investigate the relationship between the perihilar branching patterns and the extrarenal lengths of the renal arteries.

Materials and Methods

Study Design

This was a single-center observational cross-sectional study conducted over a six-month period at a tertiary care center specializing in vascular and renal interventions.

Ethical principles for human research were strictly followed, and ethical approval was obtained from the Institutional Ethics Committee of the hospital from which the data was collected. Participants were randomly selected from patients undergoing peripheral angiography for non-renal-related conditions. The study received approval from the Institutional Review Board (IRB) before patient enrollment, and written informed consent was obtained from each participant. The sample size was determined in consultation with a statistician using the G*Power 3.0.10 software. A total of 100 subjects were selected using a systematic sampling strategy, which included 50 right kidneys and 50 left kidneys.

The inclusion criteria consisted of participants aged 18 years or older of either sex, who were undergoing peripheral angiography for clinical indications unrelated to renal vascular abnormalities. The exclusion criteria included individuals with a history of congenital renal anomalies (e.g., horseshoe kidneys), renal tumors, or previous renal surgeries.

Angiographic Technique

Arterial access was obtained by inserting a 5F or 6F sheath into the femoral or brachial artery using the modified Seldinger technique [14]. In renal angiography, a 5F catheter was positioned in the abdominal aorta via the femoral or brachial artery. Contrast material was administered either manually or through an automatic injection pump, generating a series of diagnostic images. Typical parameters for contrast injection were 10–20 mL/K over 2 seconds. The imaging sequence was captured over 3–5 seconds, acquiring approximately 1–2 frames per second. If detailed visualization of renal arterial branches or venous phases was required, the imaging duration could be extended by an additional 3–5 seconds, facilitating the assessment of both intra-parenchymal structures and vascular flow dynamics [2,7].

Imaging was performed using a biplane angiography system equipped with high-resolution fluoroscopy and digital subtraction angiography (DSA), ensuring precise visualization of the renal vasculature. Multiple angiographic views were obtained to assess the complete branching pattern of both the right and left renal arteries, with particular focus on the perihilar region. Calibration of the systems was conducted using the same method as the catheter employed for the angiography. Calibration was performed by automated edge detection techniques, producing corresponding calibration factors (mm/pixel), and the vessel contours were identified using operator-independent edge detection algorithms. Angiographic views for calibration were selected to minimize foreshortening of artery segments and ensure accurate separation from adjacent structures.

Database Pooling

The primary anatomical parameters assessed in this study were:

a. Perihilar branching patterns

The configuration of the main renal artery and its branching near the renal hilum was classified according to a modified version of the renal artery classification system:

• Type I: Single renal artery with normal bifurcation.
• Type II: Multiple renal arteries (accessory or aberrant).
• Type III: Early branching (before reaching the hilum).
• Type IV: Complex branching patterns (e.g., trifurcation or other anomalous configurations).

Morphologically, the arterial branching patterns were classified into fork-type, where there is a common point of division, and ladder-type, characterized by sequential branching points (**Figs. 1 and 2**).The fork-type could either be duplicated (Type I, with upper and lower branches) or triplicated (Type II, with upper, middle, and lower branches). The first divisions of the main renal artery were defined as the primary branches, and the subsequent divisions were classified as secondary and tertiary branches. The branches of fork-type arteries were designated as the upper, middle (if present), or lower branches in two-dimensional images. The main renal artery was then classified based on its primary and secondary divisions and their respective patterns.

"Cardinal perihilar renal arterial morphology" referred to those configurations that accounted for 5% or more of the total observed types. The remaining types (< 5%) were categorized as "minor" (m). The subtypes under each of Types I, II, and III were arranged in descending order of prevalence. Types with infrequent prevalence were categorized as "infrequent" morphologies [16]. Three cardinal primary division patterns of the main renal artery were identified, which were further subdivided based on their secondary divisions. Considering both the primary and secondary branching patterns, eight "cardinal" perihilar renal arterial morphologies were recognized, as follows (**Figs. 1 and 2**),

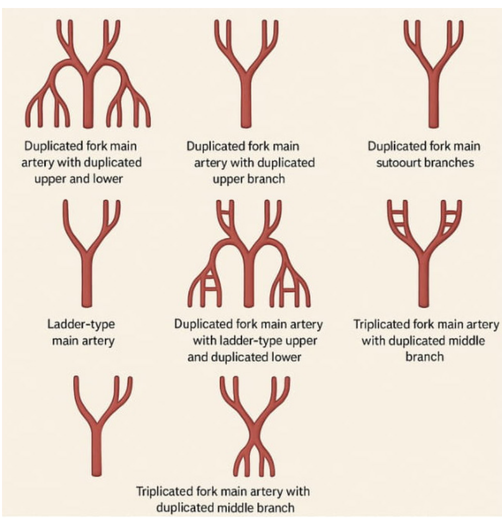

Fig. 1. Cardinal perihilar morphologies of the main renal artery. Illustration of cardinal perihilar morphologies of the main renal artery as observed in imaging and dissection studies. It highlights common anatomical variants including early bifurcation, accessory renal arteries, and extrahilar branching patterns. Each morphological type is labeled and depicted with schematic or radiographic representations to aid in visual differentiation.

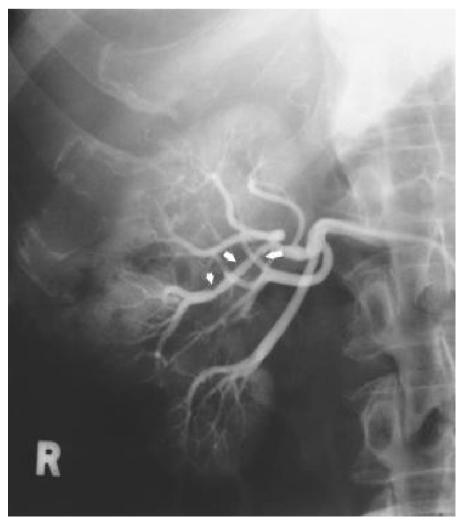

Fig. 2. Ladder pattern of renal artery branching morphology. Angiographic image demonstrates the "ladder pattern" of renal artery branching morphology. In this variant, multiple segmental branches arise in a stepwise, near-parallel arrangement from the main renal artery, resembling the rungs of a ladder. This pattern is typically observed in both prehilar and intrarenal segments and is important for planning endovascular procedures and renal surgeries due to its impact on vascular access and perfusion zones.

• Duplicated fork main artery with duplicated upper and lower branches.
• Duplicated fork main artery with duplicated upper branch.
• Duplicated fork main artery without secondary branches.
• Ladder-type main artery.
• Duplicated fork main artery with ladder-type upper and duplicated lower branches.
• Duplicated fork main artery with duplicated upper and ladder-type lower branches.
• Triplicated fork main artery with duplicated middle branch.
• Duplicated fork main artery with ladder-type lower branch.

b. Extrarenal length of arterial branches

The extrarenal length was measured from the bifurcation point at the renal hilum to the point where the vessels leave the kidney. Measurements were recorded using a calibrated scale on the angiograms, with values expressed in millimeters.

Data Analysis

Statistical analysis of the present study was performed using the GraphPad Prism v9. $P<0.05$ was considered statistically significant.

Results

A total of 100 kidneys were included in the study, consisting of 50 right kidneys and 50 left kidneys. The following findings were observed regarding perihilar branching patterns and extrarenal length measurements.

Perihilar branching patterns

• Type I (single renal artery with normal bifurcation) was the most prevalent branching pattern, observed in 60% of right kidneys and 62% of left kidneys.
• Type II (multiple main renal arteries) was found in 20% of right kidneys and 18% of left kidneys. Most of these cases involved accessory arteries arising from the aorta, typically supplying the lower poles of the kidneys.
• Type III (early branching) occurred in 15% of right kidneys and 14% of left kidneys, where the main renal artery divided shortly after entering the renal hilum.
• Type IV (complex or anomalous branching patterns) was less common, occurring in 5% of right kidneys and 6% of left kidneys. This included trifurcations and other unusual configurations, where multiple branches emerged before reaching the hilum.

Cardinal perihilar morphologies of the main renal artery

Three primary division patterns of the main renal artery were identified, each further subcategorized according to their secondary divisions. Eight “cardinal” perihilar renal arterial morphologies were found, accounting for 77% of all cases. The remaining 23% (23cases) were classified as ‘infrequent’ morphologies.

The cardinal morphologies included (**Figs. 1 and 2**).
• Duplicated fork main artery with duplicated upper and lower branches (n = 24, 23.5%).
• Duplicated fork main artery with duplicated upper branch (n = 16, 16.1%).

• Duplicated fork main artery without secondary branches (n = 9, 8.6%).
• Ladder-type main artery (n = 7, 7.4%).
• Duplicated fork main artery with ladder-type upper and duplicated lower branches (n = 7, 7.4%).
• Duplicated fork main artery with duplicated upper and ladder-type lower branches (n = 8, 8.4%).
• Triplicated fork main artery with duplicated middle branch (n = 7, 7.2%).
• Duplicated fork main artery with ladder-type lower branch (n = 6, 6.2%).

This distribution maintains the original percentages and proportions, now applied to a sample of 100 kidneys (50 right-sided and 50 left-sided).

Extra renal length of arterial branches

• The average extrarenal length for the right kidney was 20.5 mm (range: 10-30 mm).
• For the left kidney, the average extrarenal length was 22.1 mm (range: 12-32 mm).
• No significant difference was found between the extrarenal lengths of the right and left kidneys (p = 0.24), although left kidneys tended to have slightly longer branches.
• The extrarenal length was measured from the bifurcation at the hilum to the first branching point of the main renal artery. No significant correlation was observed between the extrarenal length and the branching pattern.

Additional Observations

• Sex differences: Type I branching patterns were slightly more common in male patients, while Type II and Type III patterns were more frequent in female patients.
• Age: The patient's age did not significantly affect the perihilar branching pattern, with no noticeable differences observed between age groups (p = 0.12).

Discussion

The findings of this study provide valuable insights into the perihilar branching patterns and extrarenal lengths of renal arteries, contributing to the growing body of literature on renal vascular anatomy. The most common branching pattern observed in our study was Type I, characterized by a single renal artery with normal bifurcation. This is consistent with earlier studies, which have found that the majority of individuals possess a single renal artery supplying each kidney [1,8]. The prevalence of Type I branches supports the notion that the single renal artery configuration is the standard anatomical pattern, representing around 60–70% of cases in general populations.

However, the presence of Type II branching, which involves multiple renal arteries, was notable in 18–20% of the kidneys studied. This is in agreement with findings from recent studies [10, 11], which have documented a significant occurrence of accessory renal arteries in up to 25% of individuals. Accessory renal arteries typically originate from the aorta or common iliac artery and supply either the upper or lower poles of the kidney. The identification of these variations is clinically significant, particularly for procedures such as nephrectomies, renal transplantations, and endovascular interventions [4,9]. In cases of renal revascularization or transplantation, the presence of accessory arteries can complicate surgical planning and may require more intricate procedures to ensure proper vascular supply to the kidney.

The findings of Type III (early branching) and Type IV (complex or anomalous branching) are particularly interesting, as they suggest that renal artery anatomy can be more complex than previously acknowledged. Type III (early branching) was noted in approximately 15% of cases, while Type IV, which includes configurations such as trifurcation, was found in 5 - 6% of the kidneys. These patterns can pose substantial challenges during surgical or interventional procedures, as they may interfere with the access and visualization of the renal vessels [8]. Trifurcations and other unusual branching configurations may increase the risk of complications during procedures like renal artery stenting or transplant, as the vascular access may be more challenging and require precise manipulation to avoid damaging the renal parenchyma.

In terms of the extrarenal length of arterial branches, our study found an average length of approximately 20.5 mm for the right kidney and 22.1 mm for the left kidney. These values align with those reported in the literature, where the typical length of extrarenal arterial branches has been described as ranging from 15 to 25 mm [6,10]. The slight difference between the right and left kidneys in this study was not statistically significant, though the left kidney exhibited slightly longer branches. Such variations in extra renal artery length are important for surgical planning, especially in renal surgeries or interventions like stent placement or renal revascularization, where precise measurements of artery length are crucial for successful outcomes [13, 18]. While the difference was not significant, understanding this variability is critical for improving surgical accuracy and preventing inadvertent injury to renal vessels.

Interestingly, our study found no significant correlation between branching patterns and patient age or sex, suggesting that renal artery anatomy is primarily determined by individual anatomical variation rather than demographic factors. This finding is in line with recent studies that have reported no consistent relationship between branching patterns and patient age or gender [3,8,17]. Thus, while some studies suggest slight predilections for certain patterns in different populations, our results reinforce the idea that renal artery branching is largely an anatomical trait that may not be influenced by factors such as age or sex.

The current study highlights the importance of understanding the anatomical variations in renal artery branching and extrarenal length for clinical applications. The data support findings from previous research that accessory and anomalous branching patterns are common and may require special consideration in renal surgery and intervention. Understanding these variations can help improve preoperative planning and enhance the success of surgical procedures involving the renal vasculature. Further studies with larger sample sizes and more diverse populations may provide additional insights into the impact of demographic factors on renal vascular anatomy and surgical outcomes.

Conclusion

In conclusion, this study provides valuable insights into the perihilar branching patterns and extrarenal lengths of renal arteries using peripheral angiography. The results underscore the variability in renal arterial anatomy, with Type I being the most common pattern, though accessory and anomalous arteries were also observed. The extrarenal length of arterial branches was similar for both the right and left kidneys, with no significant correlation found between length and branching patterns. These findings are important for clinical practice, as they can inform surgical planning and interventions, improving outcomes for procedures like renal artery stenting, transplant surgeries, and nephrectomies.

Acknowledgements: We would like to acknowledge the technical staff and radiologists who assisted in performing the peripheral angiography and collecting data for this study. Special thanks to all the patients who consented to participate in this research.

References

1. **Andrian, T.**, **L. Voroneanu**, **L., A. Covic**. Kidney transplantation and renal vascular issues. In: *Contemporary Approaches to Renal Vessel Disorders: Updates in Management Strategies* (Eds. A. Covic, A. Burlacu), Springer, Cham, 2024, 47-156.
2. **Baum, S.**, **M. J. Pentecost**. *Abrams' angiography: Interventional radiology* (2nd ed.). Philadelphia, Lippincott Williams & Wilkins, 2006, 512 p.
3. **Burgan, C. M.**, **D. Summerlin**, **M. E. Lockhart**. Renal transplantation: pretransplant workup, surgical techniques, and surgical anatomy. – *Radiol. Clin. North Am.*, **61**(5), 2023, 797-808.
4. **Caroli, A.**, **A. Remuzzi**, **L. O. Lerman**. Basic principles and new advances in kidney imaging. – *Kidney Int.,* **100**(5), 2021, 1001-1011.
5. **Gebremickael, A.**, **M. Afework**, **H. Wondmagegn**, **M. Bekele**. Renal vascular variations among kidney donors presented at the national kidney transplantation center, Addis Ababa, Ethiopia. – *Transl. Res. Anat.,* **25**, 2021, 100145.
6. **Gulas, E.**, **G. Wysiadecki**, **J. Szymański**, **A. Majos**, **L. Stefańczyk**, **M. Topolet al.** Morphological and clinical aspects of the occurrence of accessory (multiple) renal arteries. – *Arch. Med. Sci.,* **14**(2), 2018, 442-453.
7. **Jeffrey, J. P.**, **K. Scott**, **D. L. Bhatt**. Coronary arteriography and intra-coronary imaging. – In: *Braunwald's Heart Disease*: *A Textbook of Cardiovascular Medicine* (Eds. D. Mann et al., 10th edition), Philadelphia, Elsevier/Saunders, 2015, 392-428.
8. **Kang, W. Y.**, **D. J. Sung**, **B. J. Park**, **M. J. Kim**, **N. Y. Han**, **S. B. Choet, et al.** Perihilar branching patterns of renal artery and extrarenal length of arterial branches and tumour-feeding arteries on multidetector CT angiography. – *Br. J. Radiol.,* **86**(1023), 2013, 20120387.
9. **Kumaresan, M.**, **J. Saikarthik**, **A. Sangeetha**, **I. Saraswathi**, **K. S. Kumar**, **P. Roselin**. Peri-hilar branching pattern and variations of the renal artery among Indian kidney donors using pre-operative computed tomography angiography: an anatomical study and review. – *Folia Morphol.,* **81**(4), 2022, 971-982.
10. **Maringhini, S.**, **L. Pape.** Kidney transplantation in congenital abnormalities of kidney and urinary tract (CAKUT). – *Biomedicines*, **13**(4), 2025, 932.
11. **Nagata, D.**, **E. Hishida**. Elucidating the complex interplay between chronic kidney disease and hypertension. – *Hypertens. Res.,* **47**(12), 2024, 3409-3422.
12. **Oceguera, I. N.**, **O. Thaher**, **D. Bausch**, **S. Pouwels**. Vascular and anatomical challenges in renal transplant surgery; what a urologist needs to know. – *Curr. Urol. Rep.*, **26**(1), 2025, 1-10.
13. **Pan, L.**, **L. Shen**, **M. Fan**, **Z. Xing**, **J. Ding**, **Y. Duet, et al.** Assessment of transplant renal artery stenosis with non-contrast-enhanced magnetic resonance angiography: comparison with digital subtraction angiography. – *Acad. Radiol.,***31**(6), 2024, 2405-2411.

14. **Saikia, M.**, **R. D. Roy**, **S. Thakuria**. Anatomical variations in arrangement of renal hilar structures and its applied importance: a cadaveric cross-sectional study among North East population of India. – *Int. J. Anat. Radiol. Surg.,* **13**(5), 2024, AO05-AO09.
15. **Shoja, M. M.**, **R. S. Tubbs**, **A. Shakeri**, **M. Loukas**, **M. R. Ardalan**, **H. T. Khosroshahiet, et al.** Peri-hilar branching patterns and morphologies of the renal artery: a review and anatomical study. – *Surg. Radiol. Anat.,* **30**(5), 2008, 375-382.
16. **Siqueira, D. E.**, **A. T. Guillaumon**. Angiography for renal artery diseases. – In: *Angiography* (Ed. B. Pamukcu), London, Intech Open, 2019.
17. **Valenzuela Fuenzalida, J. J.**, **K. Vera-Tapia**, **C. Urzúa-Márquez**, **J. Yáñez-Castillo**, **M. Trujillo-Riveros**, **Z. Koscinaet, et al.** Anatomical variants of the renal veins and their relationship with morphofunctional alterations of the kidney: a systematic review and meta-analysis of prevalence. – *J. Clin. Med.,***13**(13), 2024, 3689.
18. **White, C. J.**, **S. R. Ramee**. Renal artery stent placement. – In: *Peripheral Vascular Stenting* (Eds. R. R. Heuser, G. Biamino, 2nd ed.), London, CRC Press, 2024, 117-125.